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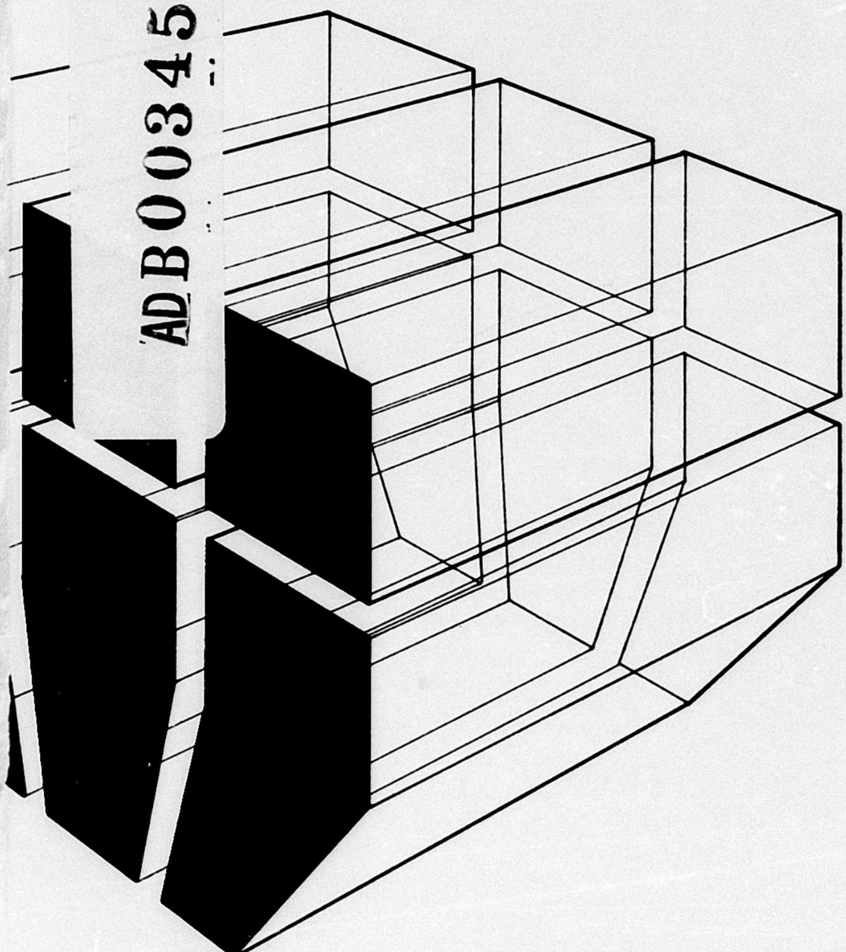
TECHNICAL REPORT E-55
April 1975

USE OF REFUSE AS A FUEL AT FORT MONMOUTH, NJ



By
H. G. Rigo

CERL

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This report analyzes the feasibility of using refuse-derived fuel (RDF) in the school boiler plant at Fort Monmouth, NJ, and the desirability of modifying the Monmouth County shredder facility to produce RDF. The County can produce RDF by adding an air classifier to its existing shredding facility. Fort Monmouth can convert existing boilers to RDF firing by installing reciprocating grate stokers and a baghouse for air pollution control. Both the County and Fort Monmouth would make

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a profit. The County would also reduce the amount of land required for the aerobic disposal of shredded refuse. The project is ecologically sound since renewable fuel resources would be used at Fort Monmouth. Design criteria for the boiler plant modifications are included. Capital and life-cycle cost estimates for both RDF production and use are presented.

FOREWORD

This study was conducted under Inter Army Order HISA-H from the Electronics Command of the Army Materiel Command at Fort Monmouth, NJ. The work was performed by the Environmental and Energy Systems Division of the Construction Engineering Research Laboratory (CERL), Champaign, IL.

Special appreciation for their cooperation and assistance is expressed to Leo Spano of Natick Laboratories; Phil Dolinsky and Art Grant, the project engineers for Fort Monmouth; and John DeGroot, Head of Utilities at Fort Monmouth.

COL M. D. Remus is Commander and Director of CERL and Dr. L. R. Shaffer is Deputy Director.

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USE OF REFUSE AS A FUEL AT FORT MONMOUTH, NJ

1 INTRODUCTION

Background. Fort Monmouth houses the Headquarters of the U.S. Army Electronics Command, an Army Materiel Command function. The Electronics Command's research and development center and one of its schools are also located at Fort Monmouth.

In FY74, during the oil embargo, Fort Monmouth had difficulty procuring fuel oil. Since that time, the cost of fuel oil has risen from approximately 12¢/gal in early FY74 to more than 35¢/gal in FY75. The reduced availability and high cost of fuel oil prompted the Electronics Command to identify potential alternate fuels for use at Fort Monmouth.

In FY74, Fort Monmouth requested that Natick Laboratories evaluate the feasibility of using the base as a test bed for its refuse recycling concept. The Natick study defined the quantity and quality of refuse being generated at Fort Monmouth. Finally, the study optimized a refuse processing facility. Implicit in Natick's work were the assumptions that the boilers at Fort Monmouth could fire refuse-derived fuel (RDF) and that additional refuse could be obtained from the surrounding community.

Subsequently, Fort Monmouth personnel determined that the oil-fired boilers in the school boiler plant were initially designed for conversion to coal firing and that Monmouth County was installing a municipal shredder facility. Thus, the capability of using solid fuel in the boiler plant and the availability of a supply of RDF were tentatively confirmed.

In view of the potential for using refuse-derived fuel at Fort Monmouth, the apparent availability of a large supply of preshredded refuse, and the spiraling cost of fuel oil, Fort Monmouth decided to investigate the problem in greater detail.

Scope of Work. As a result of the conceptual work done by Natick Laboratories and the initial feasibility study performed by Fort Monmouth, CERL was asked to:

a. Determine how to utilize RDF in the school boiler plant at Fort Monmouth. This included defining necessary boiler house modifications, fuel requirements, RDF handling systems, and air and water pollution control equipment.

b. Assess the potential for obtaining RDF from the Monmouth County shredder. This work involved a review of the processing line at Monmouth County, recommendation of changes needed in that processing line to yield RDF instead of shredded garbage, and contract content recommendations including RDF purchase price and supply and delivery schedules.

Approach. The engineering feasibility study for using RDF at Fort Monmouth proceeded in three steps. First, the capability of the existing boilers in the school boiler plant to burn RDF was determined. The method of RDF combustion, air and water pollution implications, and the siting of major pieces of new equipment were defined. Construction cost estimates were also developed.

The second stage of work involved determining the availability of RDF from the Monmouth County shredder. Construction drawings for the County shredder facility were obtained. The method of incorporating an RDF processing line into the facility was determined, and the economics of preparing RDF for use at Fort Monmouth were assessed.

The economics of using RDF at Fort Monmouth and the preparation of RDF at the Monmouth County facility were considered concurrently to determine the feasibility of the concept. Purchase price for RDF was then computed.

2 FINDINGS

The findings of this study will be presented in two subsections. These are the preparation and delivery of RDF by Monmouth County, and the utilization of RDF at Fort Monmouth.

County Shredder Facility. Monmouth County is constructing a municipal refuse shredder facility. This facility houses two 40-ton/hr Eidal Corp. Model 1000 refuse mills, magnetic separators to recover ferrous material, and stationary compactors to load shredded material onto trucks for transportation to the final disposal site. The process flow in the municipal shredder facility is as follows: refuse is delivered to an on-grade delivery floor, then moved by front-end loaders from the delivery area to the feed conveyors of the refuse grinders. Refuse is shredded until the largest particles pass a 3 in. screen. Shredded refuse then moves from the bottom of the shredder on a belt conveyor, passing under a magnetic separator where cans and other ferrous materials are recovered. Finally, the shredded refuse is placed in the feed hoppers of a pair of stationary compactors where it is loaded onto trucks for transportation to the disposal site.

The mode of ultimate disposal, called aerobic landfilling, is to spread shredded refuse over the ground. This method has been practiced successfully in Madison, WI and is being started in many other cities. Monmouth County anticipates using approximately 90 acres of land during the life of the shredder facility.

Proposed Modifications. Since construction of the processing plant is nearly complete, it was assumed in this study that the plant was operational. As a result, the addition of RDF processing equipment to the shredding facility was handled as a retrofit operation.

The only major additions to the existing plant needed to produce RDF are an air classifier and grit screen. Figure 1 shows a plan for the addition of this equipment to the existing process plant; Figure 2 is an isometric projection of the needed modification.

The equipment recommended for installation at the Monmouth County shredder facility is similar to that used by St. Louis, MO, to prepare RDF for the Union Electric Company. The design concept is to insert a high-lift flight conveyor between the shredder and the magnetic separator. This conveyor moves the shredded refuse to a disc screen where most of the dirt, grit, and glass cullet smaller than 3/8 in. in diameter is removed. The screen also serves as a feed apparatus to the air classifier where combustible and noncombustible materials are segregated.

The material leaving the top of the air classifier is called the light fraction and consists primarily of paper and cardboard with plastic film and shattered pieces of wood and twigs. This fraction also contains particles of dirt and grit which are sufficiently small to follow the air stream.

The light fraction is taken to a cyclone separator where the RDF is deposited in the feed hopper of the new compactor station. Compactor trucks then transport the RDF to the purchaser.

The heavy fraction, which falls out of the air classifier, contains large sticks, rocks, pieces of glass larger than approximately 3/8 in. in diameter, tin and aluminum cans, brass, and other material too heavy to follow the air column. Chloride-bearing plastics are also in this fraction since polyvinyl chloride (PVC) does not shatter in the coarse shredder.

This heavy material is collected on the existing conveyor belt beneath the air classifier. The heavies are then transported under the existing magnetic separator and discharged to the existing compactors. The heavy material remaining after magnetic separation is taken to the aerobic landfill site for disposal. This is approximately 30 percent by weight and 10 percent by volume of the incoming solid waste.

Economic Analysis of Preparing RDF at Monmouth County. The County shredder facility is designed to process 80 tons of refuse per hr.

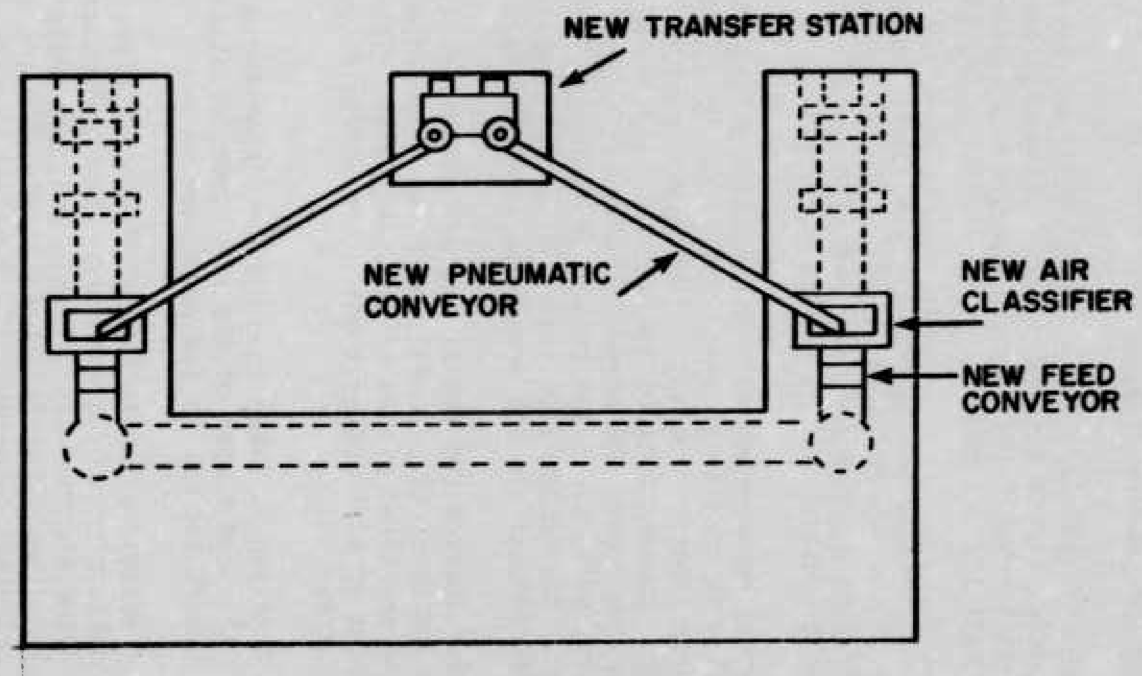

Figure 1. Proposed modification of Monmouth County shredder facility.

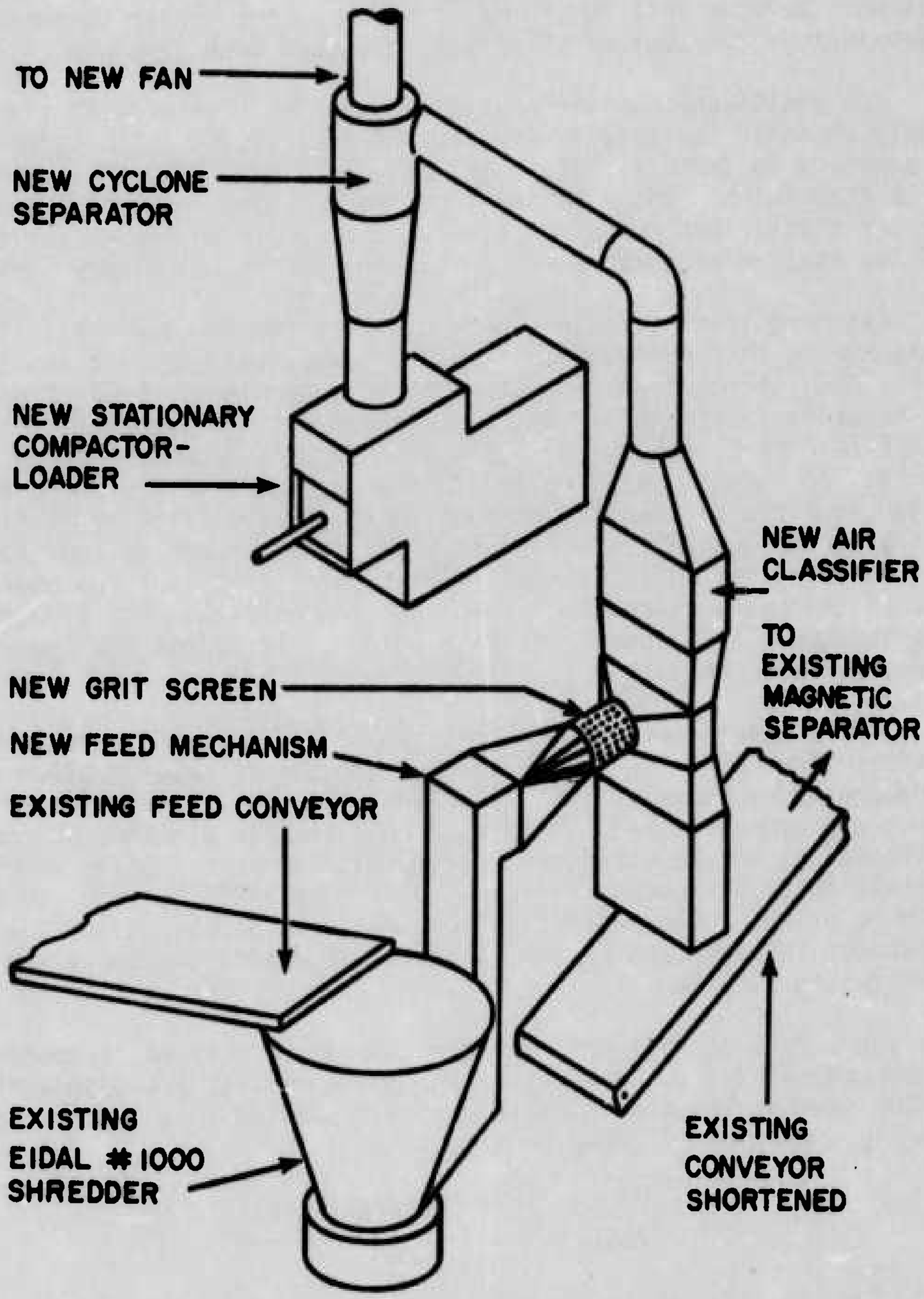

Figure 2. Isometric projection of proposed modification to Monmouth County shredder facility.

Assuming that the initial design point of the facility was based on a 5-hr operating day with the ultimate capacity being an 8 to 10 hr operating day, the Monmouth County shredder facility, upon start-up, is expected to receive approximately 400 tons of unprocessed refuse every day. If the refuse characteristics of Monmouth County are similar to those of St. Louis, MO, then 70 percent of the material delivered to the shredder will be separated into the light fraction. Thus, under current conditions, approximately 280 tons of RDF can be produced each day.

The additional capital investment that must be made at the Monmouth County shredder facility to prepare RDF is $979,000. The budget estimate is detailed in Table 1. The cost includes a new 50-by-50 ft building to be located in the center of the U of the existing facility (Figure 1), the air classifiers and disc screens, the receiving hopper for the RDF, and two stationary compactors to load the RDF into delivery vehicles.

Assuming that Monmouth County modifies the shredder facility and sells RDF to Fort Monmouth and another buyer, the economic feasibility of the Monmouth County RDF system can be determined. Table 2 delineates the annualized life-cycle cost computation for the preparation and sale of RDF to Fort Monmouth and to any other buyers Monmouth County can locate. The gross operating and maintenance cost of the shredder facility is $59,400/yr more than the cost of operating the existing facility. If Fort Monmouth guarantees the County sufficient income to amortize the shredder facility modification in 10 yr, and to pay for the operating cost of the extra processing, then Fort Monmouth must pay $193,500/yr. This is equal to an annual purchase price of $7.17/ton for the RDF needed by Fort Monmouth.

Fort Monmouth needs approximately one-third of the annual RDF production. The remaining 45,000 tons of RDF can be sold to other users. If Monmouth County sells this additional material at the same price, then a net operating and maintenance cost savings of $456,600 for the modifications to the shredder facility will be seen. After amortizing capital, this is a potential annual profit of $322,500 from the production and sale of RDF. The benefit-to-cost ratio is 5.5:1. After the capital investment is amortized (after the first 10 years) the annualized profit increases to $456,500.

The effect of sale prices other than $7.17/year was computed using the procedure used to build Table 2 and the results are displayed in Figure 3. Any savings investment ratio can be converted to an approximate annualized profit using the equation

$$\text{ALCC} \approx \frac{(S/I_n)(\text{Capital Cost})}{20} \qquad \text{[Eq 1]}$$

where:

ALCC = the annualized life cycle cost
S/I_n = the savings investment ratio
Capital Cost = the facility first cost.

Table 1

Monmouth County Shredder Modification

DESCRIPTION	QUANTITY a	UNIT PRICE b ($000)	UNIT INSTALLATION ($000) c	ENGINEERING ESTIMATE ($000) a(b+c)
Building	50 x 50	$27/ft^2		67.5
Surge Bin				
Conveyor				
Disc Screen				
Air Classifier				
Ducting	2	150	150	600.0
Cyclone				
Fan				
Foundations				
Outlet Hopper	1	20		20.0
Compactor	2	45		90.0

DATE PREPARED Jan 75

SUBTOTAL 777.5 (1)

ENGINEERING & PROFIT [0.26 X(1)] 202.2 (2)

GEOGRAPHIC FACTOR [(0.0-1.0)X(1)] -- (3)

BUDGET ESTIMATE [(1)+(2)+(3)] 979.7 (4)

Table 2

Monmouth County Shredder Modification

OPERATING AND MAINTENANCE COST ELEMENTS	QUANTITY	UNITS	UNIT PRICE ($000)	___YR INFLATION FACTOR	ANNUALIZED COST ($000)
(COSTS)					
Electricity	30	hp	.021/kwh	1.07	0.5
Fuel (Heating)				1.64	10.0
Labor	1	Man	10,000	1.00	10.0
Maintenance				1.05	38.9

(CREDITS)					
Sale to Ft. Monmouth	27,000	ton	$7.17	1.00	193.5
Sale to Others	45,000	ton	$7.17	1.00	322.5

DATE PREPARED Jan 75 NET O&M -456.6 (5)

BUDGET ESTIMATE ($000) 979.7 (6) AMORTIZED(10 %, 10 YRS) 159.5 (7)

ANNUALIZED LIFE CYCLE COST[(5)+(7)] -297.1

SAVINGS INVESTMENT RATIO $\left[\frac{10 \text{ YR. x (5)}}{(6)}\right]$ 4.6:1.0

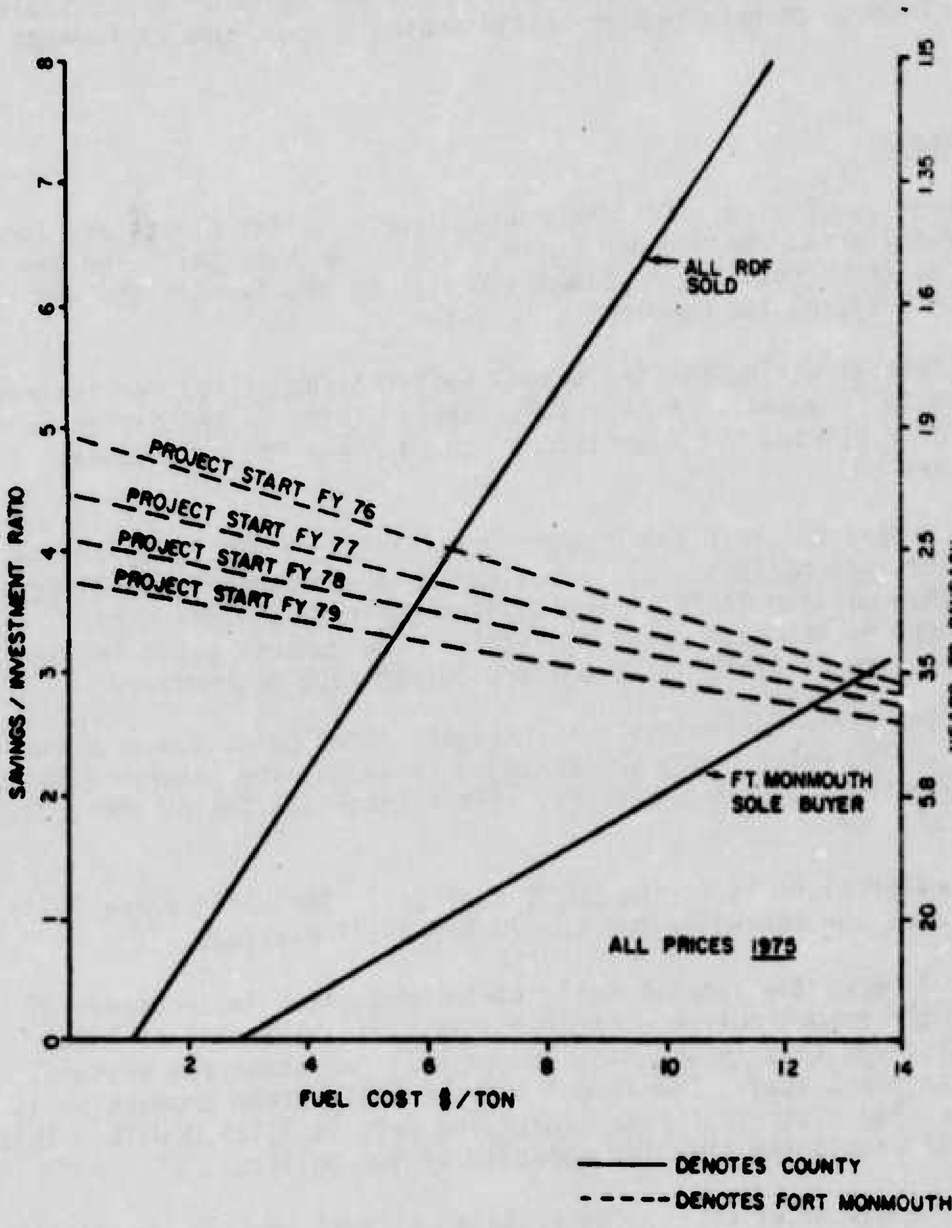

Figure 3. Savings investment ratio for Fort Monmouth and Monmouth County as a function of RDF purchase price.

In addition to the profit that the County will realize from the sale of RDF, two major additional benefits will result. The first benefit is a reduction in the amount of space required for the aerobic landfill. This will enable the County to use public lands for other purposes or to extend the life expectancy of the shredder-landfill system. The second major advantage is the political value of no longer wasting refuse; instead, the County is using the valuable combustible portion of waste to help reduce United States' dependence on foreign oil.

Fort Monmouth

Current Facilities. Fort Monmouth's three boiler plants are located in the school area, the Hexagon Building, and the hospital. The one of interest is the school boiler plant since it is the largest and was originally designed for conversion to coal.

The initial design for the school boiler plant called for the ready conversion to fire coal. As a result, space exists in the bottom of the furnace for a stoker, and foundations are in place for a bottom-ash handling system.

The school boiler plant houses four Titusville 580 boiler horse power water-tube boilers. These boilers have a maximum heat release rate of 34.9 million Btu/hr. The boilers generate a maximum of 29,000 lb/hr of 100 psig saturated steam. The exhaust gases leaving the boilers are at 625°F. The boilers do not have economizers.

The Titusville boiler has a slant-tube, three pass, two-drum configuration. The water tubes are arranged in an in-line pattern with two refractory baffles within the tubes. The furnace section of the boiler is refractory set.

The boiler plant is firing No. 6 fuel oil. The boilers are fully automated, but are manned by two men 24 hr/day, 7 days/wk.

Table 3 shows the average daily steam production in thousands of pounds for the school boiler plant for 1972, 1973, and part of 1974. Figure 4 displays this information graphically and shows the seasonal variation of plant load. The annual average daily steam production is 585,000 lb. The historical peak production rate is 1,126,000 lb. This peak is well within the steaming capacity of two boilers.

With the advent of energy conservation efforts in FY74, prediction of actual steam requirements for the school boiler plant becomes difficult. The approach taken in this study is to assume that FY74 is a good predictor of future heat rate requirements, since future winters will probably be more severe than the mild winter of 1974 and since the effect of conservation procedures will increase.

Table 3

Average Daily Steam Production*
at Fort Monmouth School Boiler Plant

	1972	1973	1974
Jan	1,060	936	752
Feb	1,241	907	846
Mar	1,037	857	788
Apr	849	654	698
May	613	537	428
Jun	365	259	251
Jul	297	299	
Aug	289	301	
Sep	340	366	
Oct	724	485	
Nov	818	643	
Dec	860	711	

*Steam production expressed in thousands of pounds.

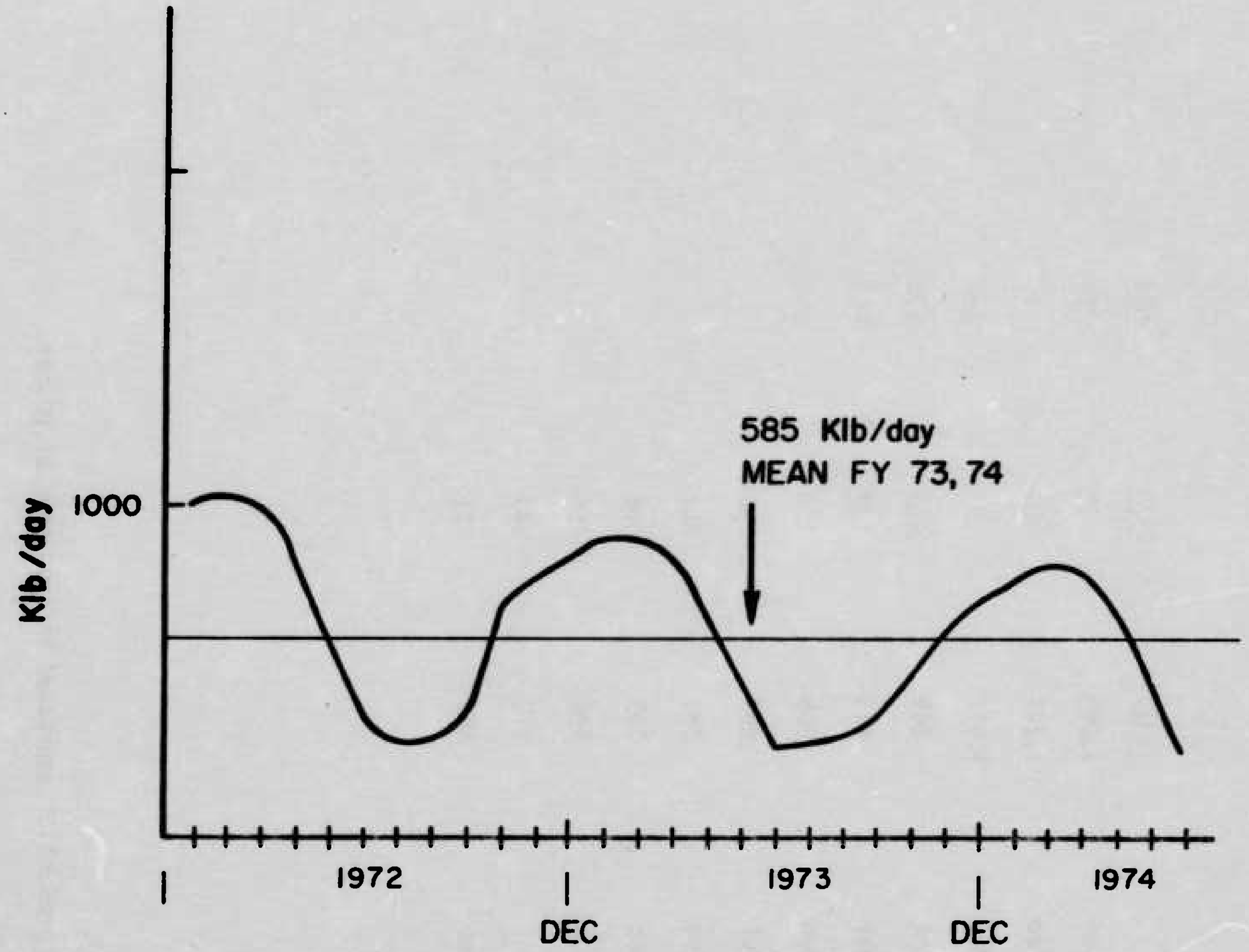

Figure 4. Average daily steam production at Fort Monmouth school boiler plant.

Space is available for new construction near the school boiler plant. A parking lot for the school buildings and a 500 ft square plot of land devoted to the temporary erection of communications training equipment are located beside the plant. Relocating the parking lot would probably be an inconvenience to the users, but relocation of the training equipment is certainly possible. This would provide space for both RDF and ash silos, and air pollution control equipment.

Process Description and Component Evaluation for Use of RDF at Fort Monmouth. Since RDF is partially homogenized and to a large extent stabilized, it is a comparatively innoxious material which is not a public nuisance. It does present handling difficulties and will degrade if allowed to get wet or if held in storage for long periods of time--2 to 3 weeks. No odor or public nuisance problems are anticipated for the Fort Monmouth RDF utilization facility if the system is properly engineered and operated.

The RDF handling and utilization sequence for the proposed modification is displayed in Figure 5. RDF is delivered in 75-cu yd transfer trailers from the Monmouth County shredder facility to an on-grade dump floor. It is moved with a front-end loader to a covered belt conveyor which transfers the material to storage.

The storage bin holds 300 tons of RDF, a 2 1/2-day supply at peak steaming rate. To prevent RDF handling problems, the entire bottom of the storage bin is traversed by the withdrawal mechanism and RDF withdrawal is continuous. Finally, the walls of the storage bin are flared outward toward the bottom to prevent material bridging.

Material is extracted from the RDF storage bin through two separate fuel outfalls. The RDF is metered into separate pneumatic conveying systems which transport the fuel along a portion of the over-fire air to a pneumatic feeder in the boilers. Use of pneumatic feeders in the boilers results in a partial spreader-stoker operation; that is, finely divided organic fractions (dust) will be combusted in suspension over the fuel bed. Heavier material will fall out of the carrier gas stream and be burned to completion on a reciprocating grate stoker.

Installations using reciprocating grate stokers have experienced refractory cracking problems. If the reciprocating grate stoker is properly isolated from the refractory walls, no cracking problems will result. Several installations in the United States have used these stokers successfully to achieve near complete combustion of shredded or unshredded municipal-type refuse in refractory furnaces.

After the RDF is burned, the residual ash is conveyed by the stoker into a dry ash receiving pit. Clinker grinders are provided to prevent any possible bridging of the ash hopper. Grinders also size the material for pneumatic transfer to a 50-ton capacity ash storage silo.

The combustion products from the firing of RDF contain large quantities of particulates and very small amounts of sulfur oxide,

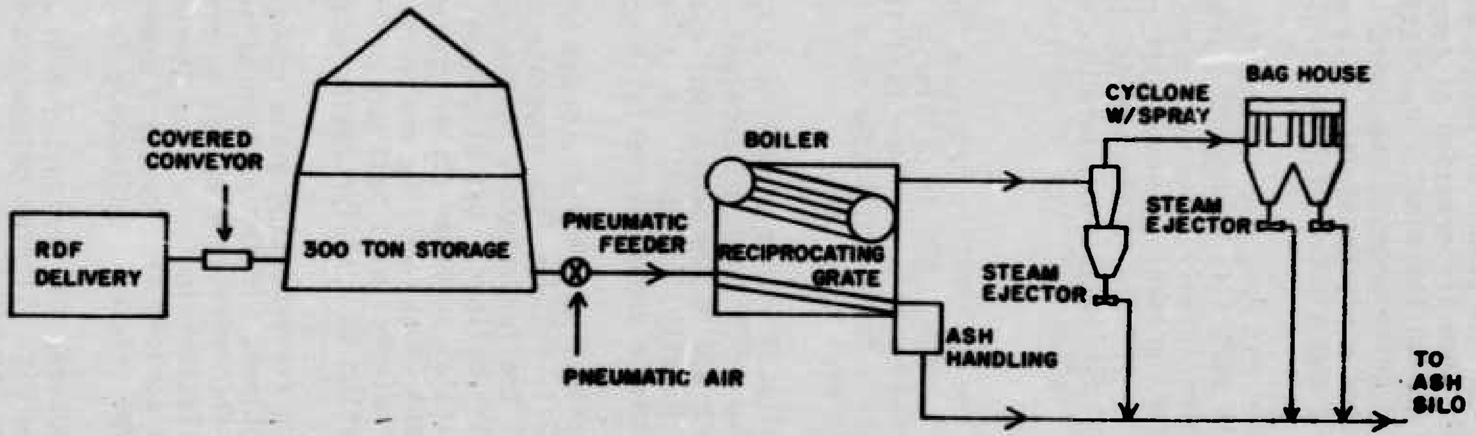

Figure 5. RDF utilization sequence for Fort Monmouth.

nitrogen oxide, and chlorides. Sulfur dioxide is not formed because very little sulfur is present in RDF. Oxides of nitrogen are minimized by the low temperatures achieved in the furnace. Chloride emissions are minimal since most chlorides in municipal refuse are in PVC plastics which are removed from the fuel fraction by air classification. The off-gases do, however, contain large quantities of fly ash; emission rates as high as 1 to 4 grains per standard cu ft have been observed. Electrostatic precipitators and scrubbers are incapable of adequate contaminant removal for the particle size range and gas characteristics generally encountered in incinerator or refuse-derived fuel systems without creating secondary pollutant problems or expending large quantities of energy. In order to control air contaminant emissions, and to achieve the mass emission rate required by the New Jersey Air Pollution Control Commission (9 lb/hr or 0.26 grains/standard cu ft), a baghouse type system must be employed.

The baghouses that have been employed successfully on incinerators are generally reverse-pulse units. The bags are woven from either teflon or teflon-coated glass fibers. The baghouse must be preceded by a medium efficiency cyclone to prevent large hot particles ("sparklers") from penetrating the bags and burning holes in them. The cyclone is equipped with a water spray to serve as an emergency quench if severe over-temperature conditions occur.

The use of baghouses on the RDF boilers at Fort Monmouth has the advantage of yielding a dry dust for ultimate disposal. If scrubbers are employed, then some form of water treatment has to be added, and the ash silo installed for handling the bottom ash cannot be used for the storage of ash from the pollution control equipment.

When dry fly ash from incinerators is handled improperly, explosive conditions can occur. These conditions result because RDF fly ash is carbonacious and finely divided. If a mechanical draft pneumatic system is used to handle this fly ash, an explosive dust mixture can form in the duct work. The use of steam ejectors instead of mechanical draft systems eliminates the explosion hazard by introducing water vapor which coats the particles with a moist surface layer.

Disposal of the fly and bottom ash collected in the ash silo poses no difficulties. This material is biologically inert and is good landfill or cover material. It can be disposed along with any unsold RDF at the county landfill, or it can be used to cover bulky refuse which has not been shredded and must be landfilled in a conventional manner.

The final subsystem to be installed at Fort Monmouth is the transfer station consisting of a compactor designed to load the trucks delivering RDF. The station is erected beside the receiving building. A ramp is built up to the transfer station inlet with surrounding ground contoured to minimize runoff. Refuse collected on post is taken to the transfer station and loaded into the empty compactor vehicles used to deliver RDF from the County facility to Fort Monmouth. While not strictly necessary

for the operation of an RDF plant at Fort Monmouth, installation of the transfer station can significantly reduce Fort Monmouth's refuse disposal cost because empty trucks will be returning to the County shredder facility.

Refuse-Derived Fuel Requirements

• Furnace Considerations. One of the primary considerations involved in the use of RDF in an existing facility is the capability of the boilers in that plant to accept the alternate fuel. While there are many considerations, including space limitations and the retrofit of peripheral appurtenances, they are of secondary importance. Unless the boilers can fire RDF, the system is unworkable. Three primary design parameters must be examined. These are flame impingement, corrosion, and slagging.

Flame impingement is not expected to be a problem at Fort Monmouth. Since the refuse will be pneumatically injected into the furnace, all small material will be rapidly burned in suspension above a burning fuel bed. Larger material will fall to the grate and complete combustion while being transported to the ash-handling system. The furnace volumes within the boilers at Fort Monmouth are large enough to allow complete combustion before the combustion products pass near the tubes. Refractory degradation can be eliminated if the boilers are not cycled on- and off-line frequently and if high silica and/or aluminal refractory materials are used. The problems of flame impingement on refractory lining have been resolved for incinerators and boilers.

Corrosion of the boiler tubes is not expected to be a problem at Fort Monmouth. Rapid corrosion occurs primarily if the RDF contains large quantities of chloride-bearing materials and the tube metal surfaces are hotter than 500°F. Fortunately, the chloride-bearing plastics are primarily PVC's which are removed when the shredded municipal refuse passes through an air classifier. Hence, there is virtually no chloride-bearing plastic in the RDF. The boilers at Fort Monmouth produce 100 psig saturated steam. The tube metal surface temperature is approximately 375°F. Hence, even if large quantities of chlorides are present, no significant corrosion is expected.

The final consideration is slagging, which is the depositing of molten ash on convective tube surfaces. If allowed to go unchecked, the slag can build up until it bridges the gap between the tubes. A positive means of slag control is to use soot-blowing equipment to remove accumulated material. The boilers at Fort Monmouth are presently equipped with soot blowers. A second means of slag control is to reduce the flue gas temperature so that the material approaching the convective section of the boiler is solid rather than molten. Solid material tends to rebound from a tube instead of sticking. There are many ways of cooling the approach gases. One method is air quenching--the use of large quantities of excess air.

Excess air reduces the temperature of gases in the furnace by adding additional masses which must be heated by the combustion process (Figure 6). Air quenching is not desirable because every pound of excess air heated from ambient temperature to furnace temperature wastes the equivalent of 1 percent of the input fuel. Losses result from emitting gas from the boiler above atmospheric temperatures.

Another way of controlling furnace temperatures is by using radiant heat transfer from the combustion products prior to the gas entering the convective section of the boiler. If it is assumed that 3 percent of heating value of the fuel introduced into the furnace is lost due to inefficiencies in combustion and another 4 percent of the heat release is dissipated through the side walls of the furnace, then by computing the radiant heat transfer from the fuel bed to the visible portion of the convected tube bank, it can be determined that at 50 percent excess air, adequate quenching results.

In order to insure that boiler degradation does not occur, it has been assumed that 100 percent excess air will be used during the combustion of refuse-derived fuel. Use of 100 percent excess air instead of 50 percent excess air decreases overall boiler efficiency approximately 3 percent. It also guarantees that molten material will not approach the tubes.

Tube configuration is another important aspect of the slagging problem. To use an ash-bearing fuel in a boiler, the tubes should be aligned with unblocked gas passes through the boiler. The tube configuration at Fort Monmouth satisfies this requirement.

The approach gas velocity of the combustion products to the tubes should be low. It is impossible for the molten ash to leave the gas stream and deposit on the tubes from slowly moving gas streams. Several engineering rules have been advanced for selecting the proper velocity. In a conventional boiler burning bagasse or wood, a design point of 43 ft/sec is recommended. Recent experience with incinerators indicates, however, that an approach gas velocity of 10 ft/sec is much safer. Under peak firing conditions, the approach gas velocity is only 8 1/2 ft/sec in the boilers to be converted at Fort Monmouth.

- Fuel Comsumption. Given the performance characteristics of the boiler system, it is possible to compute the overall input/output efficiency. Once this is determined, the amount of fuel required to produce a specified amount of steam also becomes known.

Assuming that 97 percent burnout can be achieved in the boilers at Fort Monmouth; that 11 percent losses are incurred along the side walls and convective passes of the boilers; and that the flue gas exit temperature from a new economizer is 400°F, then the input/output efficiency of the boiler becomes known. Figure 7 displays the calculated input/output efficiency of the boiler plant at Fort Monmouth as a function of excess air. Also, since the plant produces 100 psig saturated steam,

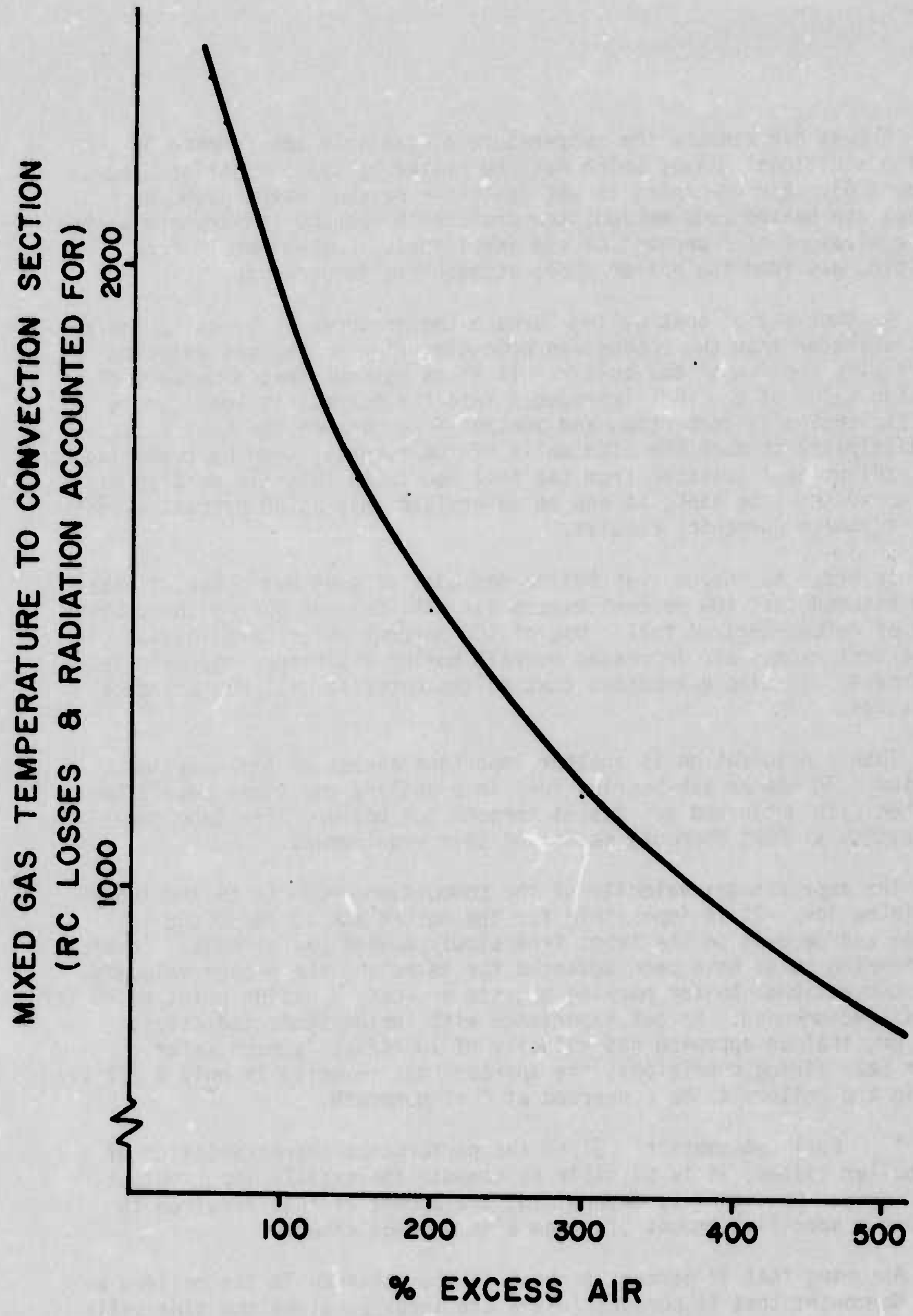

Figure 6. Furnace gas temperatures (°F) as a function of excess air.

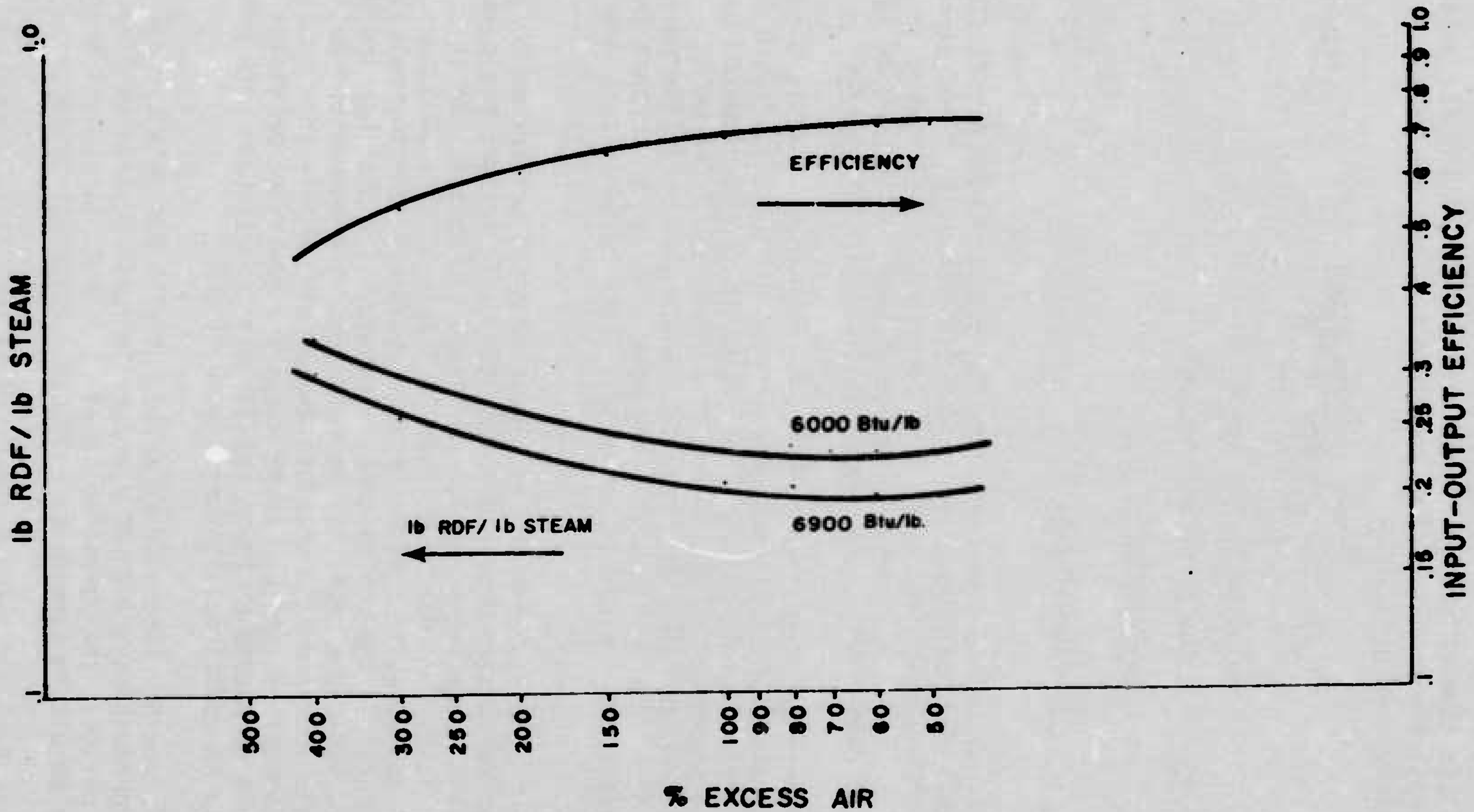

Figure 7. Fuel consumption and efficiency as a function of excess air.

and the feed water temperature is approximately 180°F, then, for various excess air levels, the amount of fuel required to produce a pound of steam can be determined using Eq 2.

$$Lb_{fuel} = \frac{h_{steam} - h_{feed\ water}}{\eta_{I/O} \times Btu/lb\ fuel} \qquad [Eq\ 2]$$

where h_{steam} = enthalpy of the steam

$h_{feed\ water}$ = enthalpy of the feed water

$\eta_{I/O}$ = boiler efficiency

Btu/lb_{fuel} = heat value of RDF

Figure 6 shows the fuel requirements for 6000 and 6900 Btu/lb RDF. Fuel requirements and boiler efficiency for Fort Monmouth at 100 percent excess air can be readily determined from the figure. Efficiency is 70 percent. The amount of fuel required ranges between 0.21 and 0.24 lb of RDF/lb of steam, depending on the higher heating value of the RDF.

Using the average daily steam production rate data in Table 3 and the boiler efficiency and fuel requirement data displayed in Figure 6, the amount of fuel required daily at Fort Monmouth can be computed by month. Table 4 shows the amount of fuel that must be burned on an average day each month. The amount of fuel which must be delivered to Fort Monmouth each working day of a 5-day week in order to support the heating requirement of the boiler plant on a 7-day basis is also presented.

To insure that Fort Monmouth can always fire its boilers on RDF, the recommended guaranteed delivery rates which will support the peak monthly and daily steam requirements are listed in Table 4. On an average day in July, Fort Monmouth needs 35.9 tons of RDF; 50.3 tons of RDF have to be delivered to Fort Monmouth each working day to meet its steam requirements for the entire week. However, if a peak heating day is encountered, additional fuel may be required. The guaranteed delivery level of 55 tons is based on a probable 2-day peak monthly fuel requirement. Comparing the amount of fuel purchased under the guarantee provision to that which would be needed by the plant if long-term storage were practical, results in only an additional 25 tons a week of RDF.

If Fort Monmouth enters into an agreement with Monmouth County whereby Fort Monmouth pays $270,000/yr for the fuel required to fire the two converted boilers, the guarantee level is a good planning estimate for the County to use in agreements with other potential consumers.

Economic Analysis of Using Refuse-Derived Fuel at Fort Monmouth. The capital cost of converting two of the boilers in the school boiler plant at Fort Monmouth to use RDF is $1,738,300. This cost estimate

Table 4

Recommended Guaranteed Delivery of RDF

	1000-lb	Tons Per Day (7-Day Week) TPD_7	Tons Per Working Day TPD_5	Daily Guarantee By Month
Jul	298	35.9	50.3	55
Aug	295	35.6	49.8	55
Sep	353	42.6	59.6	65
Oct	604	72.8	102.0	105
Nov	731	88.2	123.4	130
Dec	786	94.8	132.7	135
Jan	844	101.8	142.5	150
Feb	876	105.6	147.9	150
Mar	823	99.2	138.9	145
Apr	676	81.5	114.1	120
May	483	58.2	81.5	85
Jun	255	30.8	43.1	50

Guarantee 26,975 tons/yr

includes the receiving building, transfer station, storage for both RDF and ash, RDF feeders, boiler setting modification and grate, and ash handling and air pollution control equipment. The cost of the major elements is presented in Table 5.

In addition to the capital cost of the Fort Monmouth RDF receiving, storage, and combustion facilities, the Fort or the County will have to invest in two tractors and three compactor trailers. Table 6 displays the first cost of purchasing that equipment and Table 7 presents the annualized life-cycle cost of transporting the RDF from the County shredder facility to the Fort. Regardless of who actually purchases the vehicles and hires the drivers, Fort Monmouth will have to pay the RDF transportation costs.

The first cost of the tractors and trailers is $101,500. The annualized life-cycle cost is $99,000. This is equivalent to a per ton transportation cost of $3.67.

The annualized life-cycle cost of using RDF obtained from Monmouth County is presented in Table 8. Power is estimated by summing motor horsepower and lighting requirements. Two additional employees provide labor for RDF delivery and additional maintenance; normal plant operation can be handled by the present staff if the RDF plant is properly automated. Assuming that the contract between Fort Monmouth and the County will include a guaranteed delivery rate as outlined in Table 4, the average annual operating and maintenance cost before credits is $443,200.

Taking credit for the long-term purchase price of No. 6 fuel oil based on the current price of $0.36 per gallon and a 20-yr average cost multiplier of 1.64 (explained in Appendix B), an annual credit of $894,900 can be realized. This credit is conservative since a credit for delivered steam could be taken; the actual credit is underestimated by 54 percent. A refuse hauling credit of almost $90,000 can be realized if Monmouth County processes the refuse without charge. Free refuse-processing would be expected since the Fort would be buying it back as RDF. Transporting an extra 20 tons/day of raw refuse will have a negligible incremental cost because empty trucks will be moving from Fort Monmouth to the shredder. This results in a net annual cost of operating the boiler plant of -$541,700.

If the capital investment is amortized at 10 percent interest over 20 yr, the annualized life-cycle cost of owning and operating an RDF fired boiler plant at Fort Monmouth is a $337,500 profit. This is equivalent to a benefit-to-cost ratio of 6.2:1. Assuming a 10 percent interest rate on capital, the initial capital investment at Fort Monmouth can be repaid in 1.6 yr.

Figure 3 repeats the calculation shown in Table 8 for various RDF purchase prices; it also displays the impact of delaying the start of construction. Using a present worth analysis with commodity inflation rate i, discount rate I, project life n, and years to project start N, the

Table 5

Boiler Conversion to RDF at Fort Monmouth

DESCRIPTION	QUANTITY a	UNIT PRICE b ($000)	UNIT INSTALLATION ($000) c	ENGINEERING ESTIMATE ($000) a(b+c)
Grate, Feeder, Fan	2	40.0	40.0	160.0
Economizers	2	7.5	3.0	21.0
Ash Handling	1	300.0		300.0
Baghouse with Cyclone Pre-cleaner	2	40.0	10.0	100.0
Water Treatment	1	120.0	20.0	140.0
Boiler Resetting and Ash Pit	2	60.0		120.0
Storage Bin	1	300.0	24.0	324.0
Inlet Conveyor	1	20.0	2.4	22.4
Pneumatic Feeder	2	10.0	2.4	24.8
Delivery Building	50 x 50	$27/ft^2		67.5
Street and Apron	230	$10.34/yd^2		21.5
Scale	1	12.4	3.0	15.4
Site Preparation	1	10.0		10.0
Front-End Loader	1	8.0		8.0
Transfer Station	1	45.0		45.0

DATE PREPARED Jan 75

SUBTOTAL 1,379.6 (1)

ENGINEERING & PROFIT [.26 X(1)] 358.7 (2)

GEOGRAPHIC FACTOR [(1.0 -1.0)X(1)] -- (3)

BUDGET ESTIMATE [(1)+(2)+(3)] 1,738.3 (4)

Table 6

RDF Delivery System

DESCRIPTION	QUANTITY a	UNIT PRICE b ($000)	UNIT INSTALLATION ($000) c	ENGINEERING ESTIMATE ($000) a(b+c)
Tractor Truck	2	20		40
75 cu yd Compactor	3	20.5		61.5

DATE PREPARED Jan 75

SUBTOTAL 101.5 (1)

ENGINEERING & PROFIT [____ X(1)] N/A (2)

GEOGRAPHIC FACTOR [(____ -1.0) X(1)] N/A (3)

BUDGET ESTIMATE [(1)+(2)+(3)] 101.5 (4)

Table 7

RDF Delivery System

OPERATING AND MAINTENANCE COST ELEMENTS	QUANTITY	UNITS	UNIT PRICE ($ 000)	___YR INFLATION FACTOR	ANNUALIZED COST ($ 000)
(COSTS)					
Electricity					
Fuel					
Labor	2	men	30,000	1.0	60,000
Maintenance					
Ash Disposal					
Mileage (gas & maintenance)	312	mi/day	0.37	1.0	30,000

(CREDITS)					

DATE PREPARED Jan 75 NET O&M 90,000 (5)

BUDGET ESTIMATE ($000) 101.5 (6) AMORTIZED(10 %, 8 YRS) 19,000 (7)

ANNUALIZED LIFE CYCLE COST [(5)+(7)] 99,000

SAVINGS INVESTMENT RATIO $\left[\frac{\_\_\ \text{YR.} \times (5)}{(6)}\right]$ N/A

Table 8

Boiler Conversion to RDF at Fort Monmouth

OPERATING AND MAINTENANCE COST ELEMENTS	QUANTITY	UNITS	UNIT PRICE ($000)	20 YR INFLA-TION FACTOR	ANNUALIZED COST ($000)
(COSTS)					
Electricity	75	hp	.012/kwh	1.07	16.2
Fuel @ 100% E.A.	27,000	ton	7.17	1.0	193.6
Labor	2	men	20,000	1.0	40.0
Maintenance	5% capital			1.0	79.4
Ash Disposal	Driver & Truck				15.0
RDF Delivery					99.0

(CREDITS)					
Equivalent #6 Oil	1.7×10^6	gal	0.36	1.64	894.9
Refuse Haul & Dump				1.74	90.0

DATE PREPARED Jan 75 NET O&M -541.7 (5)

BUDGET ESTIMATE ($000) 1,738.3 (6) AMORTIZED(10 %, 20 YRS) 204.2 (7)

ANNUALIZED LIFE CYCLE COST[(5)+(7)] -337.5

SAVINGS INVESTMENT RATIO $\left[\frac{20 \text{ YR.} \times (5)}{(6)}\right]$ 6.2:1.0

YEARS TO PAYBACK = 3.8

project life offset multiplier takes the form:

$$\text{MULT} = \frac{(1 + i)^N (1 + i)^n - (1 + i)^{n + N}}{(1 + I)^{n + N} - (1 + i)^n} \qquad \text{[Eq 3]}$$

The impact of delays in project start was computed using the commodity inflation rates in Appendix B, the data in Table 8, and the project life offset multiplier.

In addition to reducing the project profit margin, program delays also reduce the probability of procuring coarse RDF from the County. Unless an agreement is reached in a timely manner, the County will probably find other buyers for its fuel.

3 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It is economical for Fort Monmouth to use RDF. A detailed engineering analysis of the school boiler plant at Fort Monmouth found that the cost of converting the existing boilers to fire RDF is $1.7 million. Fort Monmouth can achieve an average annual profit of almost $337,500 including capitalization and accounting for all assignable credits and debits while paying $7.17/ton for RDF f.o.b. the County shredder facility.

It is economical for Monmouth County to add the processing steps required to produce RDF at the County shredder facility. If the County invests the $979,000 required and Fort Monmouth guarantees to pay the County $193,500/yr for the RDF needed to support the school boiler plant, the County would gain the advantages of conserving nonrenewable resources and preserving public land for uses other than land disposal. If the County is able to find other purchasers for the RDF, a very reasonable expectation, then it can make an annual profit of $483,000, which is almost equal to one-half the initial investment.

Recommendations

Fort Monmouth should modify the school boiler plant as described in the design criteria, Appendix A of this report, subject to acquisition of an assured RDF supply.

Fort Monmouth should enter into the long-term fuel purchase contract agreement with Monmouth County in a timely manner. This will insure that Fort Monmouth has first call on the RDF and will permit the County to have its RDF production facility on-line when the Fort Monmouth RDF utilization facility is ready to start up. The contract should stipulate

that Monmouth County guarantees to deliver 27,000 tons/yr of RDF according to the schedule presented in Table 4.

Monmouth County can modify its municipal shredder facility for the production of RDF and sell that material to end users. The sale price should guarantee that the County does not lose money if Fort Monmouth is the sole purchaser. If other buyers are found, the County may be able to operate a zero-cost refuse disposal system.

Since this will be the first RDF system designed and built by DOD, but using fuel prepared by a municipal government, a detailed Environmental Impact Assessment should be prepared.

APPENDIX A:

DESIGN CRITERIA FOR THE USE OF REFUSE-DERIVED FUEL AT FORT MONMOUTH, NJ

These design criteria are based on the utilization of refuse-derived fuel (RDF) to support the steam production requirements of the school boiler plant at Fort Monmouth. The process flow (plan view, Figure A1) is as follows: (1) RDF is delivered to a receiving building by 75 cu yd compactor vehicles, (2) RDF is placed in a 2-day storage hopper, (3) the material is metered into two boilers modified for the use of RDF, and (4) the stack gases are cleaned to remove air contaminants.

1. RDF Characteristics. The RDF produced by air-classifying and screening shredded municipal refuse has a caloric value ranging between 6,000 and 6,900 Btu/lb, higher heating value. RDF contains 10 percent ash, and between 10 percent and 20 percent moisture. The RDF has a 3 in. top size.

2. Design Point. The rating of the boilers to be fired on RDF is 580 boiler hp. The boilers produce up to 29,000 lb steam/hr (150 percent of nominal rating) of 100 psig saturated steam. The load range on the boilers is a 3:1 turndown ratio.

a. The refuse receiving facility shall be designed for one-shift per day, 5 day/wk operation.

b. Utilization of the RDF shall be 24 hr/day, 7 days/wk.

c. A 2 1/2-day RDF supply at peak steam rate shall be maintained on site.

3. Regulations and Standards. Table A1 lists applicable Federal and state air pollution control laws and regulations. The most stringent of these laws and regulations shall be met. Recognizing that the applicable standards for incinerators are more stringent than the standards for industrial boilers, the most stringent applicable regulation is currently 0.08 grains of particulate matter per standard cubic foot per boiler.

4. RDF Delivery and Storage System This section of the design criteria outlines performance requirements for the delivery and storage system for the use of RDF.

a. RDF Delivery. RDF shall be delivered on-grade to an enclosed area within the RDF receiving building.

b. Front-End Loader. A 1/2 cu yd high lift, front-end loader shall be provided to move the refuse from accumulation point to the feed conveyor for the storage facility.

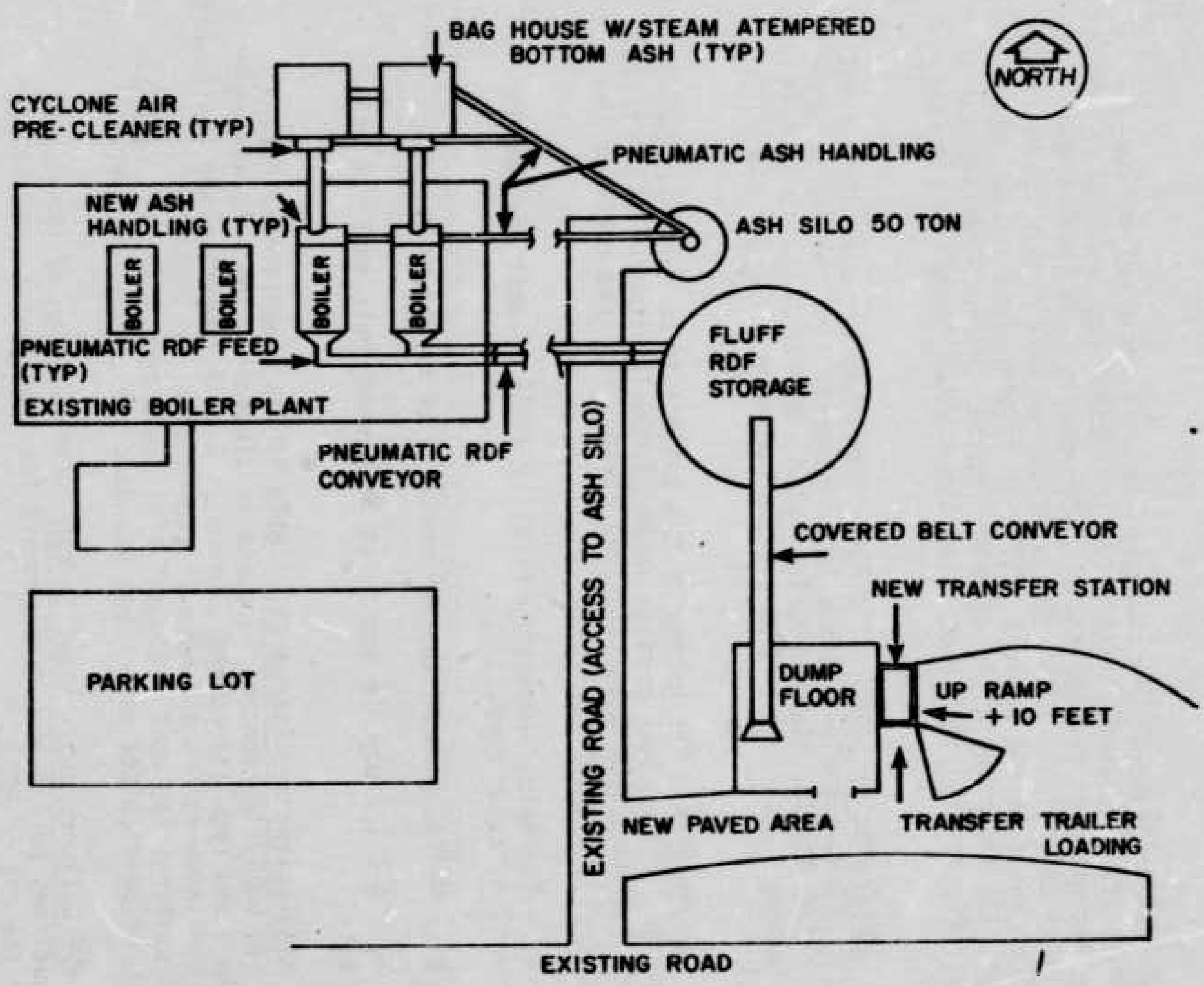

Figure A1. Site plan for use of RDF at Fort Monmouth (not to scale).

Table A1

Air Pollution Control Laws and Regulations

Source	Applicability	Allowable Particulate Emission Rate
Federal**	Fossil Fuel Boilers >7250 mm Btu/hr	0.1 lb/mm Btu
	Incinerators* >750 tons/day	0.08 gr/scf (0.16 lb/mm Btu)
New Jersey	Combustion Units 35 mm Btu/hr	9 lb/hr (0.26 lb/mm Btu)

* Applies only to volume reduction units, not to RDF boilers.

** "New Source Standards," *Federal Register* (23 December 1971), p 24877ff.

c. Feed to Storage. RDF delivery and the RDF storage hopper shall be connected by a covered belt conveyor. The feed end of the conveyor shall be below-grade. The system shall be designed so that the conveyor is self-feeding from a below-grade feed hopper to be loaded with RDF by the front-end loader.

d. Storage Hopper. The storage hopper shall be top-feed bottom extract. The hopper shall be capable of storing 300 tons of RDF. The walls of the hopper shall be inwardly inclined toward the top at a minimum of 10° from the vertical. The hopper shall have a live bottom. The live bottom shall be of the reciprocating, belt, or bucket type. The internals of the hopper and the live bottom shall be designed so that repairs can be effected without emptying the hopper. Capability shall be provided for rapid removal of RDF from a disabled hopper. Access hatches to the hopper internals shall be provided.

e. Feeder. RDF shall be taken from two fuel outfalls from the bottom of the hopper. Each outfall shall feed a separate boiler. RDF discharge shall be through a variable speed screw auger to a pneumatic feeder. The screw auger and pneumatic feeder combination shall be adjustable over a 3:1 load range to match boiler requirements. The pneumatic conveyor shall be designed so that a maximum of 20 percent theoretical air is provided by the conveying air. The pneumatic conveyors shall discharge the RDF to the furnace volume across the entire front face of the stoker. When a boiler is off-line, material from the applicable RDF outfall shall be recycled to the storage bin.

5. Fuel Combustion Equipment

a. Boiler. The four boilers in the school boiler plant are all rated at 580 boiler hp. They produce 100 psig saturated steam. Manufactured by Titusville, the boilers are of two drum water-tube design. The furnace is refractory set. The boilers were initially designed to be retrofit with coal-burning equipment. The foundations for ash handling and stokers are in place. The two boilers to the east side of the plant shall be converted to fire RDF.

b. Economizers. Boiler off-gas temperatures are 625°F. The contractor shall add economizers to the boilers being converted. The temperature of the gas leaving the economizers shall be 400°F. Economizers shall be of the cross-flow type. Tubes shall be in-line. Fin tubes shall not be used.

c. Grates. The grates shall be recriprocating stokers The stoker shall be isolated from the refractory walls. The stoker shall consist of alternating rows of grates tied to a pneumatic power source to reciprocate forward and back. Recriprocating frequency and length of stroke shall be adjustable over a 4:1 range. Between rows of moving grates, intermediate stationary bars shall be provided. All grate bars shall be fabricated from heat-treated, wear-resistant, cast iron alloys.

Potential vendors shall demonstrate a probable life expectancy on grate bars of at least 5 yr.

d. Furnace Air Control. The wind box under the grate shall be partitioned into a minimum of three zones. The wind box shall be designed to provide up to 150 percent of theoretical air requirements for the zone being controlled. Over-fire air jets shall be provided which are capable of introducing up to 100 percent theoretical air for the boiler at maximum burning rate. The over-fire air jets shall be designed to insure complete mixing of combustion products within the furnace when providing only 50 percent of their rated air capacity. Air-cooled side wall tuyeres shall be provided up to the probable fuel bed depth at maximum burning rate on each zone of the stoker.

e. Soot Blowers. Soot blowers currently in the boilers shall be repaired as required to insure that the convective surfaces can be maintained in a clean condition. Soot blowers shall be installed in the economizers.

f. Ash Handling. An ash collecting system shall be installed at the discharge end of the recriprocating grate stokers. The ash handling system shall be dry. The pneumatic transport air and bottom ash shall be taken to a separating device where the ash is discharged to a 50-ton ash silo. The carrier gas from the separator shall pass through an air cleaner. Clean off-gas shall be released to the atmosphere. The ash silo shall be designed to discharge cooled ash directly to a dump truck.

g. Fly-ash Control. Fly-ash control shall be provided. The efficiency shall be sufficient to insure that all applicable air pollution control regulations at the time of construction are met. The recommended fly-ash control equipment is a reverse pulse baghouse with spun depth media teflon or teflon-coated glass fiber bags. The baghouse shall be insulated. The baghouse shall be preceded by a mechanical cyclone collector with a 10 micron cut diameter on unit density spheres. At the contractor's option, the baghouse may treat the combined flow from both boilers converted to burn RDF or separate systems for each boiler may be installed. Ash accumulated in the hoppers below the baghouse and cyclone shall be pneumatically transferred to the bottom ash silo using steam ejectors.

6. <u>RDF Receiving Building</u>. The RDF receiving building shall be a pre-engineered insulated building approximately 50 ft square. The building shall be located northeast of the existing school boiler plant. RDF delivery shall be through the north end of the building. The delivery area shall be capable of accommodating two 75-cu yd compactor trucks simultaneously. Heat shall be provided to the building during the winter via steam unit heaters near the RDF storage hopper feed inlet. Infrared unit heaters shall be provided near the RDF delivery doors. Adequate ventilation shall be provided to insure a minimum of two air changes per hour. All interior surfaces which may be subjected to

direct contact with RDF or abrasion from the front-end loader shall be protected by a minimum of 1/4 in. steel plate. Minimum industrial lighting standards shall be met. Fire protection shall be provided by high volume deluge-type sprinklers in the RDF delivery area. All equipment and systems shall comply with the appropriate safety standards and specifications. The maximum internal noise level shall be no greater than 90 dBa.

7. Control Panel. A central control panel shall be provided along the east wall of the RDF receiving building. This panel shall bring together the controls for the entire receiving and storage areas. A controller or an operational duplicate thereof shall be located at this point. Controls for the RDF firing equipment located within the boiler house shall be at the existing control panel. RDF outfall controllers and pneumatic conveyor controls shall be located at the existing boiler control panel. An opacity meter shall be connected to the baghouse outlet to indicate failure of the baghouse.

8. Monitoring Equipment. Readouts and strip or circular chart recorders for the opacity monitoring equipment on the baghouse shall be located at the center control panel.

9. Transfer Station. A single top-feed compactor and hopper compatible with the compactors located at the County shredder shall be installed. The transfer station shall be covered by a three-sided shelter open to the east. The transfer station shall be provided with a ramp to permit direct discharge of refuse from on-post collection vehicles into the transfer station. The sides of the ramp shall be contoured and landscaped to prevent erosion.

APPENDIX B:

ECONOMIC PROJECTIONS

The future costs of energy, manpower, maintenance, and trash disposal can be predicted in several ways. Rather than trying to resolve a broad series of conflicting methods, the methods and procedures developed for the Navy by Booz-Allen and Hamilton's Energy Resource Group under Contract No. N62399-73-0029[1] will be employed. In general, it is assumed that price increases in fuels and other commodities can be modeled as an increasing exponential. The general form of this model is shown in Equation B1:

$$\$(t) = \$(0)e^{it} \qquad \text{[Eq B1]}$$

where $\$(t)$ is the value of the commodity at time t, i is the interest rate and t is time. Equation B1 can be readily manipulated to produce an effective inflation rate over a period of time if the costs at two different points in time are known.

$$i = \frac{1}{T} \ln \left(\frac{\$(T)}{\$(0)}\right) \qquad \text{[Eq B2]}$$

These costs can be expressed in either current or future dollars. If current dollars are used to express the cost of a commodity, the indicated inflation rate is smaller than if the extrapolation is based on future dollars. The two inflation rates, however, differ by a constant: the national inflation rate as opposed to the real price growth rate.

Consequently, it is imperative in comparing costs to employ the current dollar inflation rate. Table B1 was prepared from data in Chapter 7 of the Booz-Allen report.

It is also possible to assign an average cost to a commodity by recognizing that the integral of the real cost curve over a time increment divided by the time increment yields an average cost, the multiplier with which to multiply the current cost of a commodity, once the inflation rate has been specified, is the following:

$$\langle \$\text{UTILITY} \rangle = \frac{e^{iT} - 1}{iT} \qquad \text{[Eq B3]}$$

The 20-yr average price of various commodities can be computed from the data in Table B1 and the current cost of a commodity at Fort Monmouth.

[1] *Alternative Strategies for Optimizing Energy Supply Distribution and Consumption Systems on Naval Bases, Volume 1: Near Term Strategies* (Booz-Allen and Hamilton).

Table B1

Cost Element Inflation Rate and 20-Yr Multipliers

Commodity	20 Yr[1] Annualized LCC Multiplier		20 Yr[2] Present Worth Multiplier		
	$\hat{i}$	$\langle\ \rangle$	i	I	$\langle\ \rangle$
Gas	.04	1.53	7.1	10	15.41
Oil	.047	1.64	9.0	10	18.20
Coal	.04	1.53	7.1	10	15.41
Electricity	.007	1.07	0.75	10	9.01
Labor		1.0	3.5	10	11.21
Maintenance	.005	1.05	5.0	10	12.72
Landfill (contract)		1.76	8.0	10	16.59
Landfill (on base)		1.07		10	12.01
Steam		1.34			15.84
Capital	10	0.1175			1.0

---

[1] $\langle\ \rangle = \dfrac{e^{\hat{i}n}-1}{in}$ $\hat{i}$ - integral inflation rate

[2] $\langle\ \rangle = \dfrac{(1+i)[(1+I)^n - (1+i)^n]}{(1+I)^n[I-i]}$ i - inflation
I - discount rate (10%)

The 20-yr average prices for various commodities at Fort Monmouth were used in all the preceding economic analyses. Since the quality of labor required to operate the plants should remain constant over time, it was assumed that the real cost of that labor would also remain constant. This is a reasonable assumption because Federal wages are set as constant in time for a given job description; all increases for a given grade and step are based on cost of living adjustments as opposed to changes in the value of a given job structure.

The economic predictions resulting from the integral type annualizing procedure are conservative when compared to the results of a present worth analysis using equivalent interest rates applied to the same problem. The conservatism ranges between 5 and 15 percent. Hence, use of this form of economic analysis helps insure that, after start-up, the real costs will be less and the profit greater than predicted.

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